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APPLICATION FOR LETTERS PATENT

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SEMICONDUCTOR PROCESSING SYSTEM
WITH WAFER CONTAINER
DOCKING AND LOADING STATION

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CROSS-REFERENCE TO RELATED APPLICATIONS

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~~This is a continuation-in part of copending U.S. Patent Application~~

~~Serial No. 08/236,424, filed April 28, 1994.~~

TECHNICAL FIELD

This invention relates to automated semiconductor wafer processing systems for performing liquid and gaseous processing of wafers. Such systems can be used to process semiconductor wafers, data disks, semiconductor substrates and similar articles requiring very low contaminant levels.

BACKGROUND OF THE INVENTION

The processing of semiconductor wafers has become of great economic significance due to the large volume of integrated circuits, data disks, and similar articles being produced.

The size of features used in integrated circuits and data disks have decreased significantly, thus providing greater integration and greater capacity. This has been possible due to improved lithography techniques and improved processing.

The reduction in feature size has been limited by contamination. This is true because various contaminating particles, crystals, metals and organics lead to defects in the resulting products. The limitations on feature size caused by contaminants have prevented full utilization of the resolution capability of known lithography techniques. Thus there

1 remains an acute need for improved methods and systems for processing
2 semiconductor wafers, data disks and similar articles requiring very low
3 levels of contamination during processing.

4
5 BRIEF DESCRIPTION OF THE DRAWINGS

6 Preferred embodiments of the invention are described below with
7 reference to the accompanying drawings, which are briefly described
8 below.

9 Fig. 1 is a perspective view showing a preferred semiconductor
10 wafer processing system according to this invention.

11 Fig. 2 is a perspective view showing top portions of a wafer
12 holding tray used in the processing system of Fig. 1.

13 Fig. 3 is a perspective view showing bottom portions of a wafer
14 holding tray used in the processing system of Fig. 1.

15 Fig. 4 is a perspective view showing the tray of Fig. 2 loaded
16 with wafers.

17 Fig. 5 is a perspective view showing a prior art industry standard
18 wafer carrier loaded with wafers. The wafer holding tray of Fig. 2 is
19 positioned below the wafer carrier.

20 Fig. 6 is a perspective view showing portions of a wafer handling
21 subsystem used in the processing system of Fig. 1.

22 Fig. 7 is a perspective view of the subsystem of Fig. 6 moved
23 into an initial loading position with wafer carriers containing wafers
24 loaded thereon.

1 Fig. 8 is a perspective view showing the subsystem of Fig. 6
2 moved into a further position wherein empty wafer trays are passing
3 through a tray pass-through opening.

4 Fig. 9 is a perspective view showing the subsystem of Fig. 6
5 moved into a further position wherein the wafer trays have been
6 elevated up through the wafer carriers to lift wafers from the carriers
7 onto the trays.

8 Fig. 10 is a perspective view showing the subsystem of Fig. 6
9 moved into a still further position wherein the wafer trays with wafers
10 are positioned upon an upper carriage.

11 Fig. 11 is a perspective view showing the subsystem of Fig. 6 with
12 the upper carriage and supported wafers and wafer trays positioned for
13 holding until subsequently processed in the system processing chambers.

14 Fig. 12 is a perspective view of the subsystem of Fig. 6 in a
15 position similar to Fig. 7 with the emptied wafer carriers ready for
16 removal and replacement by loaded wafer carriers so that a second
17 group can be transferred in a process similar to that illustrated by
18 Figs. 7-12.

19 Fig. 13 is a perspective view showing the wafer processing system
20 of Fig. 1 with a robot conveyor loading a tray of wafers.

21 Fig. 14 is a perspective view similar to Fig. 13 with the robot
22 conveyor relocated and preparing to install the tray wafers into a
23 centrifugal processing module.
24

Fig. 15 is a perspective view similar to Fig. 14 with the robot extended into a loading position wherein the tray of wafers is installed in the centrifugal processing module.

Fig. 16 is a view showing mechanical arm portions of the robot conveyor shown in Fig. 1 extended into a laid-out position for purposes of illustration.

Fig. 17 is a view showing how the view shown in Fig. 16 is partitioned into the enlarged detail sectional views shown in Figs. 18-28.

Figs. 18-28 are enlarged detailed sectional views showing different portions of the mechanical arm of Fig. 16.

Fig. 29 is a top view showing a hand portion of the mechanical arm assembly with a tray of wafers loaded thereon.

Fig. 30 is a front view showing the hand portion of Fig. 29.

Fig. 31 is an isometric view of a preferred centrifugal processing rotor used in the centrifugal processing modules shown in Fig. 1.

Fig. 32 is a front view of the rotor shown in Fig. 24.

Fig. 33 is a front view of the rotor as shown in Fig. 32 with a wafer tray held within the rotor.

Fig. 34 is a schematic view showing functional blocks of the preferred control system used in the processor of Fig. 1.

Fig. 35 is a perspective view showing important components of the mechanical arm assembly shown in Fig. 13.

Fig. 36 is a front elevational view of an alternative processor according to this invention.

1 Fig. 37 is a side elevational view detailing an alternative
2 processing station used in the processor of Fig. 36.

3 Fig. 38 is a top view detailing the alternative processing station
4 shown in Fig. 37.

5 Fig. 39 is a rear elevational view detailing the alternative
6 processing station shown in Fig. 37.

7 Fig. 40 is a perspective view showing an alternative loading
8 subsystem in isolation.

9 Fig. 41 is a side view showing portions of a further embodiment
10 of the invention which incorporates the alternative loading subsystem
11 shown in Fig. 40. Fig. 41 shows the embodiment in a first position.

12 Fig. 42 is a side view showing the embodiment of Fig. 41 in a
13 second position.

14 Fig. 43 is a side view similar to Fig. 41 with the embodiment in
15 a third position.

16 Fig. 44 is a side view similar to Fig. 41 with the embodiment in
17 a fourth position.

18 Fig. 45 is a side view similar to Fig. 41 with the embodiment in
19 a fifth position.

20 Fig. 46 is a side view similar to Fig. 41 with the embodiment in
21 a sixth position.

22 Fig. 47 is a side view similar to Fig. 41 with the embodiment in
23 a seventh position.
24

Fig. 48 is a side view similar to Fig. 41 with the embodiment in an eighth position.

Fig. 49 is a side view similar to Fig. 41 with the embodiment in an ninth position.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

Processor Generally

Fig. 1 shows a preferred processing system 40 according to this invention. Processing system 40 includes a basic frame 41 which provides structural support for related components. Processor 40 has two fundamental sections, one of which is the interface section 43. The other fundamental section is the processing section 44.

The frame supports an enclosure envelope 45 which in Fig. 1 is shown partially removed adjacent the processing section for purposes of illustration. The enclosure envelope encloses a working space 46 within portions of processor 40. Wafers 50 are held and maneuvered within the enclosed working space. The wafers are moved between multiple processing stations 71-73 contained within the processing section 44. The working space can be supplied with a purge gas and operated at

1 either slightly elevated or slightly reduced pressures relative to ambient
2 atmospheric pressure.

3 The upper portions of processor 40 are provided with an interface
4 filter section 38 and a processing filter section 39. These filter sections
5 preferably employ HEPA type ultrafiltration filters. Air moving
6 equipment forces air through the filters and downwardly into the
7 working space to move contaminants downwardly and out through the
8 back side of the processor.

9 The multi-station processor 40 also preferably has a process
10 station maintenance section 53 which is separated from the work space
11 26 by portions of the enclosure envelope 45. Processor 40 also
12 preferably has an instrumentation and control section 54 mounted
13 rearwardly from the interface section 43. Control section 54 preferably
14 includes various control equipment used in processor 40.

15 Maintenance section 53 and control section 54 are of potentially
16 higher contamination levels due to the presence of various equipment
17 components associated with the processing stations. The processor 40
18 is advantageously mounted in a wafer fabrication facility with clean
19 room access to the front of the processor along front panel 48. The
20 maintenance and control sections are preferably accessed from the rear
21 of processor 40 through a gray room adjacent the clean room. Such
22 gray rooms have fewer precautions against contamination than the clean
23 room. This configuration reduces plant costs while allowing access to
24 portions of the processor more typically needing maintenance.

1 The front of processor 40 includes a front control panel 57
2 allowing operator control from the clean room. Control panel 57 is
3 advantageously a touch screen cathode ray tube control display allowing
4 finger contact to the display screen to effect various control functions.
5 Control section 54 also preferably includes a secondary control panel
6 (shown schematically in Fig. 34) which faces rearwardly into the gray
7 room so that operation can be affected from either front or back of
8 the machine. All control functions and options are displayed upon the
9 control panels to effect operation and set up of the processor.

10 As shown, wafers 50 are supplied to and removed from the
11 enclosed work space 46 of processor 40 using interface section 43.
12 Wafers are supplied to the interface section in industry standard wafer
13 carriers 51 (detailed in Fig. 5). The wafer carriers are preferably
14 supplied in groups, such as a group of four carriers. The groups are
15 placed upon a cantilevered shelf 101 forming a part of a first carriage
16 100. Shelf 101 extends through an interface port 56 which is
17 controllably opened and closed using a interface port door 59.
18 Adjacent the interface port and control panel is a view window 58
19 through which a human operator can see operation of processor 40.
20 Fig. 1 shows two wafer carriers 51 positioned upon the cantilevered
21 shelf 101. There are two additional positions available for two
22 additional carriers which are left unloaded in Fig. 1.

1 Wafer Tray

2 Refer to Figs. 2 and 3 which show the novel wafer tray 60 in
3 greater detail. Wafer tray 60 includes an upper surface 61 and a lower
4 surface 62. The tray also has a first end 63 and a second end 64.
5 Sides 65 extend between the first and second ends. Additional features
6 of the tray surfaces will now be more fully detailed.

7 Upper surface 61 has a series of wafer tray receivers 66. Wafer
8 tray receivers 66 each comprise a semicircular groove or channel having
9 downwardly converging receiver sides 67. The converging receiver sides
10 67 adjoin to a receiver bottom section 68 which is a relatively narrow
11 slot having substantially parallel slot walls. The slot section is sized to
12 provide a width about 0-10% greater than the thickness of the wafers
13 which are being received therein. The receiver bottom or slot section
14 has bottom surfaces 69. The lower portions of the slot sections 68 are
15 formed so as to be intermittently closed at slot bottom surfaces 69 and
16 open along receiver drain apertures 70 (Fig. 3). The slot bottom
17 surfaces 69 exist along longitudinal foundation bars 75 and side rail
18 portions 76. The particular number of wafer tray receivers 66 in any
19 particular tray 60 is variable. Typically, there will be 25 or 50 wafer
20 receivers in order to correspond with the capacity of associated wafer
21 carriers 51 being used in other parts of the fabrication plant.

22 The upper surfaces of wafer tray 60 also preferably include side
23 land portions 79. The side land portions are formed to reduce overall
24 height of the tray while maintaining the general semicircular receiver

1 shape. The overall width of tray 60 is appropriately sized so that more
2 than approximately 50° of arc are seated, more preferably approximately
3 60-80° of arc are encompassed for seating the wafers in receivers 66.
4 Even more preferably the arc of the receiving channels is approximately
5 65°.

6 The wafer tray ends 63 and 64 are preferably planar and
7 perpendicular relative to a longitudinal axis 80 (Fig. 4) which extends
8 perpendicular to the receiving grooves along the center point of the
9 receiving groove arcs defined by bottom surfaces 69. Longitudinal axis
10 80 also coincides with the centers of the wafers 50 supported on the
11 wafer tray. Tray ends 63 and 64 are advantageously provided with
12 apertures 88 for receiving a tool therein to allow handling of the trays
13 with minimum contact, such as during cleaning.

14 Wafer tray 60 has side rails 76 which extend along both sides.
15 The side rails have outer side surfaces 65 which are advantageously
16 formed to provide tray support features 80. As shown, tray support
17 features 80 include a tray side channel 81. Tray side channel 81 has
18 a downward facing bearing surface 82 which bears upon supporting tools
19 and equipment as explained more fully hereinbelow. Adjacent to
20 surface 82, is an outwardly facing channel base surface 83. Bearing
21 surface 82 is preferably constructed to form an included angle of
22 approximately 120° of arc relative to the channel base 83. Channel 81
23 further includes an upwardly facing third surface 84 which serves to
24 complete the channel shape of the tray support features and provides

1 increased structural engagement between the wafer tray and equipment
2 which engages the tray using the tray side channels 81.

3 The lower surface 62 of tray 60 is preferably formed with a
4 downwardly facing contact or foot surface 86. As shown, foot surface
5 86 defines a footprint with five longitudinal segments associated with
6 side rails 76, longitudinal bars 75, and end panels 63 and 64. The
7 lower surface of the tray also is preferably constructed to have
8 longitudinal base recesses 77 between bars 75 and side rails 76.
9 Processing fluids drain from the wafers 50 and wafer tray 60 through
10 the receiving slot openings 70 and base recesses 77.

11 The novel wafer trays 60 provide improved processing of wafers
12 in processor 40. The improvements include improved access of
13 processing fluids to the surfaces of wafers 50. The improved access of
14 processing fluids occurs because there is less coverage of the wafers as
15 compared to prior art carriers 51. Only relatively small marginal edge
16 portions along the arc of the receivers are covered. Thus allowing
17 almost full access to the faces of the wafers by processing fluids. The
18 improved access to processing fluids in turn results in reduced
19 processing times and greater uniformity and effectiveness of the
20 processes upon the surfaces being treated. Wafer tray 60 also results
21 in a small combined size of the wafer batch within processor 40. This
22 translates into a much smaller overall size of processor 40 and reduced
23 floor space requirements in clean rooms and adjacent gray rooms.
24 Since the cost of floor space in these facilities is very high, the

1 installed cost of the processing system 40 is kept relatively lower.
2 These factors all attribute to better yields, improved quality and reduced
3 costs of production.

4 5 Standard Wafer Carrier

6 Processor 40 is designed to work in conjunction with a standard
7 industry wafer carrier which is illustrated in Fig. 5. Such carriers are
8 available from a number of supplying manufacturers. Carrier 51 has a
9 holding trough 34 with a series of edge receiving receptacles 35 along
10 side walls 36. End walls 37 are typically provided with handles 38.
11 The bottom of carrier 51 is provided with a bottom opening (not
12 shown) which is rectangular and defined between base rails 39. Fig. 5
13 shows a wafer tray 60 positioned beneath wafer carrier 51 aligned to
14 pass up through the bottom opening of the carrier. Wafer tray 60 is
15 sized to pass through the bottom opening.

16 17 Interface Section

18 The interface section 43 takes the wafers from the wafer carriers
19 and installs them onto the specially constructed wafer trays 60. The
20 wafer trays provide improved processing of wafers 50. The interface
21 section also preferably provides a holding or inventorying capability for
22 both wafers awaiting processing and wafers which have been processed.
23 Thus the interface section constructed as shown in Fig. 1 functions as
24

1 both an input subassembly, output subassembly and wafer holding
2 station.

3 Interface 43 is substantially enclosed by the enclosure envelope 45.
4 Interface 43 has open work spare portions connected to the portions of
5 work space 46 contained within the processing section 44. The
6 interface includes a interface port 56 formed through envelope 45.
7 Interface port 56 allows wafers to be loaded into and removed from
8 processor 40. Interface port 56 is preferably provided with an interface
9 port closure in the form of a movable door 59. Movable door 59 is
10 powered and extends upwardly from below to close the port and is
11 retracted downwardly to open the port. This construction allows the
12 interface port door to be automatically controlled to the extent desired.

13 Figs. 6-12 show the principal operational portions of interface 43.
14 These portions serve to provide a wafer transfer which transfers wafers
15 from the industry standard wafer carriers 51 and installs the wafers onto
16 the novel wafer trays 60. Additionally, interface 43 serves to hold
17 wafer batches loaded onto the trays. These loaded tray batches are
18 held for processing in the processor. Still further interface 43 allows
19 for the storage of unloaded wafer trays. As shown, interface 43 also
20 performs loading and unloading operations through interface port 56.

21 Fig. 6 shows that the preferred interface 43 has a base 99 which
22 is secured to frame 41. A first or lower carriage 100 is mounted for
23 movements, such as the preferred horizontal movement. A second or
24

1 upper carriage 102 is also mounted for horizontal movement. Interface
2 43 also has four elevators 104 which provide vertical movement.

3 Base 99 in some respects acts as an extension of frame 41 and
4 further serves to separate the interface section compartment into an
5 interface section portion of working space 46 and a mechanical
6 compartment 98 (Fig. 1) which is below and subjacent to the working
7 space and base 99. As shown, base 99 is provided with four elevator
8 openings 102 which serve as apertures through which elevators 104
9 extend.

10 Base 99 also is provided with first carriage travel openings or
11 clefts 106. Clefts 106 receive portions of a first carriage support
12 pedestal 107 which extend downwardly from the first carriage beneath
13 base 99. The pedestal extends down to a first carriage support track
14 (not shown) which is below base 99 in the mechanical compartment 98.
15 Pedestal 107 is connected to a first carriage operator (not shown) which
16 is advantageously in the form of a rotatable linear screw drive operator
17 similar to the operator described below in connection with second
18 carriage 102.

19 Fig. 6 also shows that interface 43 includes two carriages 100 and
20 102 which are movable relative to elevators 104. Carriages 100 and
21 102 are preferably mounted for simple linear motion relative to the
22 elevators. However, alternative configurations and movement patterns
23 may be possible. Carriages 100 and 102 are independently operable or
24

otherwise controllable to allow different relative horizontal positions and movements of the first and second carriages.

As shown, first carriage 100 is positioned above base 99 and below the second carriage 102. This preferred configuration results in the first carriage functioning as a lower carriage, and the second carriage functioning as an upper carriage. Elevators 104 serve to move wafer batches between a first or upper carriage level associated with the first carriage and a second or lower carriage level associated with the second carriage.

First carriage 100 includes an outer or forward portion forming a first section 111 of the carriage. This outward section is in the form of a cantilevered shelf or carrier support projection 101. Carrier support projection 101 serves to support wafer carriers 51 thereon. First carriage 100 is laterally movable to extend the carrier projection or overhang through interface port 56 into the fully extended first carriage receiving position illustrated in Fig. 1. The overhanging carriage shelf 101 is provided with carrier support features which are advantageously in the form of carriage support ledges 109. The carrier support ledges are preferably recessed areas formed in the upper surface of shelf 101. The carrier support features are advantageously constructed to provide lateral support against unintended horizontal displacement in either X or Y directions (see Fig. 1). The carrier support features also hold the carriers to prevent downward movement

1 from a desired vertical or Z position, but allow vertical movement
2 above the shelf for easy installation and removal of the wafer carriers.

3 The carrier support ledges 109 or other carrier support features
4 are preferably positioned adjacent or about first carriage transfer
5 openings 110. The support ledges are most preferably peripheral
6 recessed areas about the opening 110. Openings 110 are provided to
7 allow extension of the elevators 104 therethrough. Extension of the
8 elevators through openings 110 is used in conjunction with the transfer
9 of wafers between the wafer carriers 51 and wafer trays 60 in either
10 incoming or outgoing directions.

11 First carriage 100 also preferably includes a second or central
12 section 112 which includes a group of four first carriage pass-through
13 openings 113. Pass-through openings 113 extend through the deck of
14 the first carriage to allow extension of the elevators therethrough. Pass-
15 through openings 113 also allow unloaded wafer trays 60 to be passed
16 upwardly and downwardly through the first carriage deck in a manner
17 as explained more fully below.

18 First carriage 100 is further provided with a third or rearward
19 section 113. Rearward section 113 includes an empty or unloaded wafer
20 tray magazine or storage 115. The empty wafer tray storage is
21 advantageously in the form of four arrays each having three receptacles
22 to receive three wafer trays therein. The receptacles each include
23 shoulder pairs which function as rests upon which the side rails 76 of
24 the wafer trays rest. The shoulder pairs are along arranged along

opposing sides of an empty tray gallery 116 which is common to all three receptacles of a single storage array 115. Galleries 116 allow the heads of the elevators to extend upwardly to engage empty wafer trays and lift them for removal from the storage array. The empty tray gallery also extends through the deck of the first carriage, and is contiguous with and open to the adjoining pass-through openings 114.

The empty tray storage is also preferably provided with an empty tray storage roof panel 117 which extends over and protects the empty wafer trays from downwardly drifting contaminating particles. The roof panels are supported by first carriage rear section support panels 118.

The first carriage is further advantageously provided with a second carriage pedestal inlet opening 119 which allows a support pedestal of the second carriage to extend thereinto when the second carriage is moved forwardly.

Interface 43 also includes the second or upper carriage 102. Upper carriage 102 has an upper carriage deck 121 which is supported by a second carriage support pedestal 122. Pedestal 122 has a linear drive operator 123 which is advantageously in the form of a rotatable screw drive 124 which moves the second carriage forwardly and backwardly between retracted and extended positions.

The upper carriage is provided to function as a loaded tray holding or inventorying station. As shown, this function is accomplished by having the second carriage in a position above the first carriage, and provided with a series of loaded tray holders 125. Loaded tray holders

1 125 are formed as receptacle ledges formed in the deck. The
2 receptacle ledges are adjacent to second carriage elevator openings 126.
3 Openings 126 are preferably portal openings which have open entrances
4 at the forward ends thereof. As shown, the upper carriage is
5 configured to hold two groups, each group having four wafer trays in
6 a four by two loaded wafer tray storage array.

7 Interface 43 also includes elevators 104 which have elevator rods
8 or shafts 128 and enlarged elevator heads 129. The elevator heads are
9 constructed to engage the lower surface 62 of wafer trays 60 in a
10 stable manner. Most preferably the upper contacting face of elevator
11 head 129 is provided with four engagement projections 130 at the front
12 and back of the contacting face. The engagement projections are
13 spaced and sized to fit within the longitudinal recesses 77 of trays 60
14 adjacent the end panels. This provides positive engagement against
15 lateral displacement of the trays relative to the elevator head during
16 automated handling of the wafer trays by the interface.

17 Interface 43 is advantageously constructed to handle wafer carriers
18 and wafer trays in groups or gangs of four at a time. Although this
19 configuration is preferred, it is alternatively possible to have other gang
20 sizes.

21 22 Operation of Interface Section

23 The operation of interface 43 will now be described in connection
24 with the series of drawings shown in Figs. 7-12. Fig. 7 shows the

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1 interface moved from the fully retracted positions of Fig. 6 into an
2 initial loading position wherein the first carriage has been extended fully
3 to position the overhanging carrier shelf 101 through the interface port
4 56. Fig. 7 also shows the carrier shelf loaded with four wafer carriers
5 51 containing wafers 50. The carriers and wafers are positioned in the
6 carrier support receptacle ledges 109 over the wafer transfer openings
7 110. The second carriage 102 is maintained in the fully retracted
8 position.

9 After the wafer carriers have been loaded onto shelf 101, the first
10 carriage is retracted. When sufficiently retracted, the interface port
11 door 59 is closed by extending the door upwardly. The first carriage
12 continues to retract rearwardly until the elevator head 129 is aligned
13 with the stored trays held in empty wafer tray storage arrays 115. At
14 this tray pick position, the first carriage is stopped and the elevators
15 are aligned below the stored wafer trays. The elevators are then
16 extended upwardly to engage and lift the lowest empty trays from the
17 four storage arrays. The elevators are then stopped and held at a tray
18 lift elevation position.

19 The first carriage is then retracted further to bring the pass-
20 through openings 114 into alignment with the elevators and elevated
21 empty wafer trays positioned upon the heads of the elevators. At this
22 pass-through position of the first carriage, the first carriage is stopped.
23 The elevators 104 are then retracted downwardly to pass the empty
24

1 wafer trays through the deck of the first carriage. The empty trays are
2 moved downwardly until they are below and clear of the first carriage.

3 The first carriage is then moved rearwardly from the pass-through
4 position into a transfer position. In the transfer position the first
5 carriage is positioned so that the elevators and empty wafer trays held
6 thereon are aligned with the bottom opening of the wafer carriers held
7 in carrier holders 109. Fig. 9 shows the first carriage in the first
8 carriage transfer position.

9 Fig. 9 further illustrates the transfer of wafers from the wafer
10 carriers 51 and their installation onto the wafer trays 60. In Fig. 9 the
11 elevators have been extended upwardly after the first carriage has
12 assumed the transfer position. The transfer includes aligning the
13 individual wafer receivers 66 below the wafers 50 held in carriers 51.
14 As the elevators extend upwardly, the tray moves up, into and through
15 the open bottom of carriers 51. The edges of the wafers 50 are
16 guided by the V-shaped receiver mouths having downwardly converging
17 receiver side surfaces 67. The edges of wafers 50 are guided by the
18 receiver mouths into the relatively close fitting receiver slots or channels
19 68. The edges of the wafers bear against the wafer slot bottom
20 surfaces 69. The bearing allows the wafers to further be lifted
21 upwardly by the elevating trays 60.

22 Fig. 9 shows the elevators fully extended with trays 60 fully
23 elevated and with wafers 50 held in an aligned side-by-side array upon
24 the trays. In this condition, interface 43 has transferred the wafers and

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the loaded wafer trays are ready to be moved to the holding stations on second carriage 102. To accomplish this, the second carriage is extended outwardly and forwardly from the retracted position into an extended position, such as the fully extended position shown in Fig. 10. In this position the second carriage has been moved forwardly so as to align the rearward gang of loaded tray holding receptacles 125 with the elevated wafer trays. The elevators are then retracted downwardly to lower the loaded wafer trays into the receptacles 125. After the loaded trays have been received in receptacles 125, the second carriage can then be retracted rearwardly into a retracted holding position, such as shown in Fig. 11. Fig. 11 also shows the elevators 104 fully retracted and the first carriage retracted with empty wafer carriers 51 awaiting discharge from the interface section.

Fig. 12 shows the first carriage repositioned into a fully extended carrier unload position. This position is also the initial load position shown in Fig. 7. The empty wafer carriers are removed using ~~any~~ suitable means, such as manual removal by a human operator (not shown). Loaded wafers are then loaded onto the overhanging shelf of the first carriage and the process illustrated by Figs. 7-12 is repeated for a second gang or group of carriers, wafers and trays. The second loading process differs only slightly from the process described above. One difference is that different trays are used from the empty ~~tray~~ storage magazines 115. Another difference is that the second gang of loaded trays are held in the outer or forward holding receptacles 125

1 instead of the rearward tray holders used by the first gang of wafer
2 trays.

3 4 Processing Section

5 The processing section 44 of processor 40 will now be described
6 in greater detail. As shown, processing section 44 includes three
7 centrifugal processing stations 71-73. Each processing station includes
8 a processing chamber bowl 131 which substantially encloses an internal
9 processing chamber 132. A centrifugal processing enclosure door 134
10 is mounted for controlled powered vertical motion between a closed
11 upward position and a downwardly retracted open position. Preferred
12 door constructions are shown in U.S. Patent No. 5,302,120, which is
13 hereby incorporated by reference.

14 Within each processing chamber is a suitable rotor for receiving
15 loaded wafer trays, such as rotor 133 detailed in Fig. 31. Fig. 32
16 shows a front view of rotor 133 without a wafer tray loaded therein.
17 Fig. 33 shows a front view similar to Fig. 32 with a loaded wafer tray
18 positioned within the rotor. Rotor 133 is specially constructed to
19 receive and appropriately engage wafer tray 60 using wafer tray
20 engagement features as explained below. The resulting interlocking
21 interengagement of the tray with the rotor substantially prevents
22 dislodgement until appropriately removed.

23 Rotor 133 includes three principal ring pieces 141-143. The front
24 ring 141 has a beveled rotor opening 149. The front, central and rear

1 rings are connected by connecting longitudinal bars 144 and 145.
2 Upper longitudinal bars 144 are spaced from the wafer trays 60 and
3 are provided with inwardly directed longitudinal bumpers 146. Adjacent
4 the wafer tray receptacle 136 are three additional longitudinal bars 145.
5 The inward edges of bars 145 serve to guide and support wafer trays
6 60 appropriately positioned within the wafer tray receptacle.

7 The wafer tray engagement features used in the wafer tray
8 receptacle include a rotor tray receiving channel 136. The sides of
9 receiving channel 136 include rotor tray engagement projections 137.
10 The rotor tray engagement projections are shaped and sized to
11 complement and be received along the tray side channels 81. However,
12 the tray side channels are substantially higher than the engagement
13 projects because the trays are loaded using a tray engagement tool 150
14 which inserts between the downward facing bearing surface 82 of the
15 tray and the upward surface of rotor engagement projections 137.
16 Additionally, the clearance is preferably sufficient so that engagement
17 tines 184 can also pass through the available space during insertion into
18 the rotor to retrieve a tray therefrom.

19 The wafer tray engagement features used in rotor tray receiving
20 channel 136 also include opposing side receiving flutes 138. Flutes 138
21 receive the longitudinal side flanges 85 of tray 60 in relatively close
22 fitting interengaging relationship. The bottom or foot surface 86 of tray
23 60 bears upon inwardly directed tray support surfaces 147 on the
24 longitudinal bars 145. This advantageously occurs between both outer

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1 support bars 145 with both side rails 76 of the tray, and along a
2 central tray support bar 145 and the center longitudinal foundation bar
3 75 of the tray. Central longitudinal bar 145 is advantageously provided
4 with a bumper bar 148 (Fig. 32).

5 The processing stations are each independently driven by rotating
6 assembly motors 153 and have other features of a centrifugal fluid
7 processor as needed for the desired processing of that station.
8 Additional details of a preferred construction of centrifugal processor are
9 well-known or can be taken from the attached Appendix hereto.

10 The specific processing performed in processing stations 71-73 can
11 each be different or of similar nature. Various liquid and gaseous
12 processing steps can be used in various sequences. The processor is
13 particularly advantageous in allowing a series of complex processes to
14 be run serially in different processing chambers set up for very different
15 chemical processing solutions. All the processing can be accomplished
16 without human handling and in a highly controlled working space, thus
17 reducing contamination and human operator handling time.

18 The processing section 44 also includes a processing section
19 portion of working space 46. This portion of the working space is
20 frontward of processing stations 71-73 within the enclosure envelope 45.
21 This processing section working space allows the tray conveyor described
22 below to supply and remove loaded wafer trays to and from the
23 processing stations.
24

Conveyor

Processor 40 is advantageously provided with a mechanical wafer tray conveyor 140. Conveyor 140 will be described initially with reference to Figs. 13 and 14. The preferred conveyor includes a conveyor carriage or tram 156 and a mechanical arm assembly 157 which is mounted on the tram. The tram moves the mechanical arm assembly along a defined tram travel path. The mechanical arm assembly moves the wafer trays 60 upwardly, downwardly, inwardly, outwardly, and adjusts the tilt within a range of available positions and orientations.

Tram 156 has a base 160 which connects with a base subassembly 165 which forms part of the mechanical arm assembly (see Fig. 35). The complementary base parts 160 and 165 join to provide a combined base assembly which serves as a movable base for the mechanical arm assembly.

Tram 156 moves along a guide track 258 which defines the tram path along which the tram travels. The guide track is advantageously formed by upper and lower guide bars 158 and 159 which are mounted along the outward side of a track support member 161 forming part of the frame. This construction allows the mechanical arm assembly to extend into cantilevered positions to reach processing stations 71-73 with good positional stability. The guide bars are engaged by track followers in the form of linear bearings 171 which are secured to the inward face of the tram base 160. The linear bearings 171 are advantageously

provided with rod engaging rollers spaced at equal 120° arc positions about the guide bars 158 and 159.

The tram is powered along the defined path guide track by a suitable tram driver, such as a track magnetic drive in the form of linear magnetic motor 163. Linear magnetic motor 163 is most preferably a linear brushless direct current motor. Such a preferred tram driver uses a series of angled magnetic segments which magnetically interact with an electro-magnet on the base of the robotic conveyor to propel the tram and attached mechanical arm up and down the defined path track.

The path position of the base 160 along the guide track is precisely controlled using a positional indicating array (not shown) affixed to the front of the track support member adjacent to guide bars 158 and 159. An optical emitter detector pair (not shown) are mounted upon base piece 160. The optical emitter detector pair serves as a track position sensor or indicator which reads the position of the tram base from the indicating array after proper calibration. The positional accuracy of the track position indicator is preferably in the range less than 0.003 inch (approximately less than 0.1 millimeter).

Fig. 35 shows the mechanical arm assembly 157 in a simplified form for purposes of illustrating and introducing the preferred construction. Mechanical arm assembly 157 is preferably of a type which can provide highly accurate positional stability and repeatability for precise control and movement of the loaded wafer trays which are

supported at the distal end of the mechanical arm. As shown, mechanical arm assembly 157 includes a base portion 165 which is secured to tram base piece 160. An upper arm assembly having two complementary upper arms 166 are mounted to pivot relative to the body portion 165. Upper arms 166 are preferably connected together so as to provide coincident angular movement using an upper arm connection member, such as torque tube 167. The upper arm assembly pivots with respect to the base about a shoulder pivot axis 168.

A forearm assembly is connected near the outer distal end of the upper arm assembly. The forearm assembly advantageously includes two forearms 172 which are joined by a forearm connection member 174. The forearm assembly also uses opposing face panels 173 (Fig. 15) to provide a strong and mechanically integrated forearm assembly which is resistant to twisting and provides a high degree of positional stability. The forearm assembly is connected to the upper arm assembly to allow relative pivotal movement about an elbow pivot axis 169.

The distal end portions of the forearm assembly support a hand assembly 176. Hand assembly 176 is supported in a manner allowing pivotal movement about a wrist pivot axis 170. The hand assembly includes two complementary hand bars 177. Hand bars 177 are joined together by a hand cross piece 178. The hand assembly also preferably includes a tray engagement tool 180 which is mounted to the hand cross piece 178.

1 Figs. 29, 30 and 35 show that the preferred tray engagement tool
2 180 includes a complementary pair of hand extensions 181. Hand
3 extensions 181 are advantageously semi-cylindrical sections which form
4 a cradle which engages the wafer tray 60. The hand extensions
5 preferably engage the wafer tray along the side rails, such as along the
6 outer side surfaces of the tray. More specifically, the hand extensions
7 preferably are spaced to define a hand extension gap 182 having
8 parallel inside engagement edges 183. Tool engagement edges 183 are
9 received along the wafer tray side channels 81. The tool engagement
10 edges are slid longitudinally along side channels 81 to position the tool
11 for engagement with the wafer tray.

12 The ends of the hand extensions are preferably provided with end
13 tines 184. When the hand extensions are lifted upwardly, the
14 engagement edges bear upon the downward facing bearing surface 82
15 of the wafer side channels. Simultaneously therewith, tines 184 move
16 upwardly to latch at the end of the wafer tray to prevent longitudinal
17 slippage of the wafer tray upon the hand extensions. This latching
18 places the tines along end surfaces of the wafer tray. The hand
19 extensions can advantageously be provided with perforations 185
20 (partially shown in phantom in Fig. 35) to lighten the weight of the
21 assembly.

22 The preferred construction of mechanical arm assembly 157 ~~will~~
23 now be described in greater detail with reference to Figs. 16-28 in
24 addition to other Figs. of this application. Fig. 16 shows the

mechanical arm assembly connected to tram base 160 using base pieces 165. A shoulder joint cover 313 is shown installed in Fig. 16. Similarly, an elbow joint cover 187 is shown installed about components of the elbow joint. Most of the hand assembly 176 is not included in Fig. 16 to simplify the drawing. Fig. 17 is similar to Fig. 16 except it shows how the mechanical arm 157 has been subdivided to allow enlargement and illustration of various details of the preferred construction. The detailed illustrations are sectional views presented in Figs. 18-28.

Figs. 18 and 19 show components associated with the wrist joint connection between the hand assembly and the forearm assembly. The preferred wrist joint construction includes two hand connection hubs 190 which pivot to provide tilting action of the hand assembly. Hubs 190 are either integrally connected to the hand bars 177 (as shown), or detachably connected thereto. Hubs 190 are pivotally supported relative to the forearm members 172 using hand hub support bearings 191. Bearings 191 are supported by forearms 172 against radial movement, and against longitudinal movement by capture between an outboard seal housing 192 and an inboard bearing mounting ring 193. Fasteners 194 extend through ring 193, forearm 172, and into seal housing 192. Seal housing 192 holds a hub shaft seal 195.

Hubs 190 are limited within a defined range of angular motion using a wrist hub angular displacement limiter. The angular displacement limiter is advantageously in the form of an axial pin 197

1 which fits within a pin socket 198 formed in the hub 190. Pin 197
2 extends into an annular slot 199 formed in the outer face of the seal
3 housing 192. The angular slot advantageously allows a range of motion
4 of approximately 100-120° of arc.

5 The first hub 190 shown in Fig. 18 is connected to rotate with
6 a hand drive pulley 200 using a shaft key 201 supported in associated
7 keyways formed in the hub and pulley. A spacer ring 204 is between
8 the inner race of bearing 191 and pulley 200. A pulley retainer 202
9 is fastened to the inboard end of the hub using a fastener 203 to keep
10 the pulley against axial movement.

11 Pulley 200 has cable receiving grooves 205 formed in the
12 periphery of the pulley. Hand drive cables 206 are received within the
13 grooves 205. Pulley 200 is advantageously provided with a cable
14 clamping block 207 which is set in the pulley within a recess. The
15 cable clamping block has a clamp head 208 which squeezes down upon
16 cables 206 when fasteners 209 are tightened.

17 Because of the need for highly accurate and repeatable positioning
18 of the hand assembly, it has further been found desirable to provide
19 independent bearing support for pulley 200. This can be accomplished
20 using a pulley bearing 210. Pulley bearing 210 is supported by an
21 intermediate spacer bar 211 which extends between the wrist joint and
22 the elbow joint.

23 The pulley retainer 202 is advantageously formed with a pair of
24 annular fins 213 and 214. Annular fin 213 can be moved into a

position within detector gap 215 of optical detector 216. Similarly, annular fin 214 can be moved into a position within detector gap 217 of optical detector 218. The optical detectors are mounted to the forearm cross member 174. Optical detectors 216 and 218 sense the outer bounds of desired angular travel of the hand assembly and serve effectively as limit switches providing signals to the controller operating the mechanical arm.

Fig. 19 shows that the second hub 190 is connected to an angular position encoder 220 which is mounted to cross member 174 using an encoder mount 221. The shaft of the position encoder is coupled to hub 190 using a bellows shaft coupling 222. Movements of the hand assembly relative to forearms 172 are detected with greater precision by encoder 220. A preferred encoder discriminates a 360° circle into approximately 64,000 divisions.

Figs. 22 and 23 show the elbow joint between forearms 172 and upper arms 166. The elbow joint pivots about elbow joint axis 169. Pivotal action between the upper arm assembly and forearm assembly is accommodated by two main elbow pivot bearings 225 and 226. First main elbow pivot bearing 225 is preferably a cross roller thrust bearing. Second main elbow pivot bearing 226 is preferably a ball bearing. The outer race of first main bearing 225 is connected to the upper arm 166 using a bearing support ring 227 and fasteners 228 which extend through apertures in upper arm 166. A similarly functioning bearing

1 support ring 229 and fasteners 230 are used in connecting second
2 bearing 226 to upper arm 166.

3 Bearing 225 receives within its inner race a forearm mounting
4 tube 233. Forearm 172 is secured to mounting tube 233 using fasteners
5 234. A proximate forearm cross brace 235 extends between and is
6 connected to forearms 172 using fasteners 236. Mounting tube 233 is
7 used to pivotally support a cable drive transfer shaft 240. Cable drive
8 transfer shaft 240 is supported within mounting tube 233 using a pair
9 of transfer shaft bearings 238. A tubular bearing spacer 239 extends
10 between the inner races. Bearing retainer rings 241 and 242 are
11 fastened to hold the bearings axially against the mounting tube 233.

12 The inboard end of transfer shaft 240 is advantageously formed
13 as an elbow joint transfer pulley 243. Elbow joint transfer pulley 243
14 has parallel cable receiving grooves 244 and a cable mounting block 248
15 similar to wrist joint pulley 200. The cable mounting block 248 has a
16 cable mount head 249 fastened to the pulley to secure cables 206.
17 Cables 206 extend between pulleys 243 and 200 to effect movement of
18 pulley 200 and the hand assembly.

19 Inboard transfer pulley 243 is driven by an outboard transfer
20 pulley 250. Pulley 250 is fastened to transfer shaft 240 using fasteners
21 251. Cables 252 are looped around pulley 250 and hand drive
22 transmission output pulley 255 at the shoulder pivot (see Fig. 26).
23 Pulley 255 is driven by a hand drive electrical motor 256. The output
24 of motor 256 is coupled to pulley 255 via a harmonic drive speed

1 reduction transmission 257. The frame of motor 256 is held securely
2 to the base 165 of the mechanical arm. The reduced speed output
3 from the harmonic drive controls the tilt of the hand assembly. This
4 construction allows the tilt of hand assembly 176 to stay at a fixed
5 attitude even though the upper and lower arms pivot. Thus the
6 attitude of the hand assembly only changes when the hand drive motor
7 256 is controlled to drive.

8 Figs. 22 and 23 also show an elbow joint encoder 260. The
9 casing of the encoder is mounted to the forearm assembly cross member
10 235 using an encoder mount 261. Encoder mount 261 includes an
11 isolation mount band 262 to reduce vibratory transmission to the
12 encoder. The shaft of the encoder is connected through a bellows
13 coupling 263 to an upper arm encoder coupling shaft 264. The
14 outboard end of shaft 264 is fixed to the upper arm 166 using a
15 coupling shaft mount 265. Relative angular motion between the upper
16 arm and the forearm is detected as relative angular motion between the
17 encoder case and encoder shaft. This information is provided to the
18 controller used to control mechanical arm 157. A partition plate 279
19 extends from mount 265 to help guide wiring (not shown).

20 Between encoder coupling shaft 264 and the tubular transfer shaft
21 240 is an assembly advantageously used to guide electrical wires. The
22 transfer tube wire guide includes an inboard part 266, an outboard part
23 267, and an intermediate tubular member 268. Inboard and outboard
24

1 parts 266 and 267 have passageway apertures 269 through which wires
2 are run.

3 Fig. 23 shows the forearm drive assembly 270. Drive assembly
4 270 includes a forearm drive motor 271 and a forearm drive speed
5 reduction transmission 272. The outer housing of motor 271 is coupled
6 to the forearm assembly. The shaft of motor 271 is connected to the
7 transmission 272 which is preferably a harmonic drive providing 160:1
8 gear reduction. The third connection of the harmonic drive is coupled
9 to the upper arm assembly via a harmonic drive coupling plate 273
10 using fasteners 274. The opposite, inboard, end of motor 271 is
11 provided with a motor encoder 276 which indicates operation of the
12 forearm motor 271 and provides a signal indicative thereof. A thumb
13 wheel 277 is also advantageous provided to allow manual movement of
14 the motor during maintenance and setup.

15 The elbow joint is also advantageously provided with an elbow
16 joint limit switch 278 which is tripped when the relative position of the
17 forearm reaches the limits of desired angular travel.

18 Figs. 26-28 show the shoulder joint which pivots about pivot axis
19 168. The shoulder joint provides for relative pivotal motion between
20 the base pieces 165 and the upper arm assembly. Base pieces 165 are
21 secured to tram carriage 160. Relative angular movement between base
22 pieces 165 and the upper arms 166 is supported by main shoulder pivot
23 bearings 281 and 282. First main bearing 281 is advantageously a cross
24

1 roller thrust bearing. Second main bearing 282 is advantageously a ball
2 bearing.

3 The outer race of bearing 281 is secured to the base piece 165
4 using a bearing retainer 283 which is fastened to base 165. The inner
5 race of bearing 281 is coupled to an upper arm coupling ring 285.
6 Coupling ring 285 is secured to the upper arm 166 using fasteners 286.
7 A seal 287 is advantageous positioned between bearing retainer 283 and
8 coupling ring 285. An inner race bearing retainer ring 288 is fastened
9 to coupling ring using fasteners (not shown).

10 The housing of the hand drive motor 256 is mounted to the base
11 piece 165 using bolts 290. The shaft 291 of motor 256 is connected
12 to the harmonic drive transmission 257. The casing of the harmonic
13 drive is captured between a pulley mounting ring 292 and the housing
14 of motor 256. This fixes the position of the harmonic drive casing.
15 The third or output connection of the harmonic drive is connected to
16 a pulley drive piece 294 using fasteners 295. The pulley drive piece
17 transmits torque from the output of the harmonic drive to hand motor
18 pulley 255.

19 Pulley 255 is supported for pivotal movement upon mounting ring
20 292 using bearings 296. Bearing 296 are held in axial position by a
21 bearing retainer 297 fastened to mounting ring 292 by fasteners (not
22 shown). The inboard end of motor shaft 291 is advantageously fitted
23 with a thumb wheel 298 for manual manipulation of the motor during
24 setup and maintenance. A motor encoder 299 is connected with motor

256 to provide motor response information to the mechanical arm controller which is used along with information from the hand angular position encoder 220 to provide precise control of the mechanical arm assembly.

Figs. 27 and 28 show the drive used to move the upper arm assembly relative to base pieces 165. The upper arm assembly drive includes an upper arm drive motor 301. Motor 301 has a shaft 302 which drives a harmonic drive speed reduction transmission 304. The casing of the harmonic drive is coupled securely to the housing of motor 301, both of which are secured to base pieces 165. The flexible spline or third output 303 of the harmonic drive is coupled to an upper arm drive piece 305 using fasteners 306. Drive piece 305 is connected to an upper arm bearing ring 307 which is held by the second main bearing 282. This allows the bearing ring 307 and attached upper arm pieces to pivot. Seals 310 and 311 are advantageously included to seal the enclosed motor and transmission space to reduce contamination within the working space of the processor.

The inboard end of motor 301 is provided with a motor encoder 315 and a thumb wheel 316. An upper arm drive position encoder 320 is mounted with an isolation connector 321 to a support or mount 322 which is connected to base ring 165. The shaft of the encoder is connected by a clamp 389 to an arm 388. Arm 388 connects to piece 307 to indicate angular movement of the upper arm. A limit switch

325 is positioned to trip when the upper arm assembly extends to the limits of its desired angular travel range.

Upper arms 166 are also preferably provided with outer cover pieces 312 to enclose components of the upper arm assembly. The base is provided with a base cover cylinder 313 to partially confine and facilitate enclosing the internal space which holds includes the motors and transmissions.

Control System

Fig. 34 shows a preferred control system used in processor 40. The control system advantageously uses a modular design which incorporate commercially available computer modules, such as 80486 based computers, to perform various functions. Fig. 34 shows the human operator interaction stations 331 and 332. The first station 331 has a computer processor 341 of conventional design and an electrically attached display and control panel 57. Control and display panel 57 is accessible from the front or clean room side of processor 40. The second control station 332 has a computer processor 342 also of conventional design and an electrically attached display and control panel 343 which is available for operation on the gray room or back side of processor 40. Both control stations are connected using a standard network interface hub 350. Network hub 350 is connected to a central controller, such as a computer file server 351. Hub 350 can also be used to connect an outside control or monitoring station 360 for

1 additional control capabilities, data acquisition, or monitoring of
2 processing and control functions.

3 Hub 350 is further connected to processor control modules 361-
4 363, which are also conventional computers without displays. Processor
5 station control modules 361-363 are each associated with processing
6 stations 71-73 respectively. These station control modules allow
7 independent processing routines to be run at the processing stations and
8 for data to be recorded indicating the processing performed in each
9 particular batch being run by each processing station.

10 Processing station control modules are connected to and interact
11 with the processing station motors, plumbing, etc which are collectively
12 identified with the processing station number 71-73 in Fig. 34.

13 Fig. 34 further shows an interface subsystem controller 381, which
14 again is a computer. Interface subsystem controller 381 is electrically
15 connected to various features of the interface subsystem to both control
16 operation and receive confirmatory signals of movements and position.
17 The interface controller 381 is preferably connected to the interface
18 section to receive signals through a number of optical fibers 386 used
19 to convey signals from positional encoders for the first and second
20 carriages 382, limit switches 383 which detect the limit of travel of the
21 carriages and elevators, and wafer detectors 384 which detect wafer
22 trays and wafer carriages held in the interface section. The system is
23 preferably constructed so that most or all sensed signals used in the
24 control and operation of the interface are communicated by optical fiber

1 to eliminate the risk of cross talk between signal lines. The optical
2 fiber transmitted signals are converted into electronic signals by an
3 optical fiber signal converter 387 which produces electronic signals which
4 are communicated to computer 381.

5 Fig. 34 still further shows a conveyor control module in the form
6 of a computer 391 without display which is electrically connected to
7 various parts of the conveyor, such as the mechanical arm motors 256,
8 271 and 301, encoder 220, and other components thereof not specifically
9 illustrated.

10 The conveyor control module also preferably receives a number
11 of signals through optical fibers 396. Optical fibers 396 are used to
12 convey signals from angular position encoders and motor encoders for
13 the conveyor 140 which are for simplicity exemplified by encoder 220
14 in Fig. 34. Limit switches for the conveyor are exemplified by limit
15 switch 278 in Fig. 34. Hall effect sensors 395 are used in sensing
16 operation of the motors of the conveyor. The system is preferably
17 constructed so that all sensed signals used in the control and operation
18 of the conveyor are communicated by optical fiber to eliminate the risk
19 of cross talk between signal lines and provide a smaller cable bundle
20 which is moved in connection with tram motion up and down the track.
21 The optical fiber transmitted signals are converted into electronic signals
22 by an optical fiber signal converter 397 which is connected to reconvey
23 the signals to computer 391.
24

Alternative System Configurations

Fig. 36 shows an alternative configuration of processor 400 constructed and capable of operation according to this invention. Processor 400 includes two interface sections 401 and 402, which are advantageously mounted upon opposing ends of the processing system. Interface sections 401 and 402 are substantially or identically the same as interface section 43 described above. Between the interface sections are a series of processing stations 411-415. Stations 411-413 and 415 are similar to centrifugal processing stations 71-73. Processing station 414 is of an alternative design which will be more fully described below. Other alternative constructions are also possible.

Processor 400 has a processing enclosure 430 which in part defines an interior working space 431 adjacent to the processing stations and including the interface spaces accessible to the wafers being processed.

Processor 400 can be operated to load wafer carriers at first interface station 401 and remove processed wafers in wafer carriers at second interface station 402. Alternatively, each interface station can both load and return processed wafers through their associated interface ports.

The alternative wafer submersion processing station 414 is shown in greater detail in Figs. 37-39. Submersion or immersion processing station 414 includes two processing bath or immersion tanks 501 and 502 which are in front and back, respectively. Tanks 501 and 502 are

used to hold processing liquids, such as acids and water. Tanks 501 and 502 advantageously have enlarged brims 513. Station 414 includes a frame extension 505 which is a vertical member which mounts a wafer tray dipping mechanism or dipper 507.

Dipper 507 includes a movable dipper arm 508 which moves within a channel 504 using a dipper drive (not shown). The dipper drive is preferably an X-Y (two-dimensional) electrical servo-motor powered positioning drive. Alternatively, two linear electrical servo-motor powered drives can be coupled in a perpendicular configuration to allow the horizontal and vertical motion needed to traverse the channel 504. The dipper drive is advantageously enclosed within frame extension 505.

The dipper mechanism also preferably includes a dip head 509 which, as shown, is suspended from dipper arm 508. Dip head 509 advantageously includes a dip head connector 512 which is connected to the dipper arm 508. The dip head connector is also connected to a longitudinal top member 522. Longitudinal member 522 forms part of a dipping mechanism tray holder 514.

The dipping mechanism tray holder 514 also preferably has a basket which is open, perforated or otherwise foraminous in construction so as to allow liquid movement about the wafers 50 being processed. As shown the basket includes a series of circumferential rings 521. Rings 521 are connected by a top bar 522 which is suspended from connector 512. The lower portions of the rings are connected by lower

1 longitudinal members 523 and a basket bottom piece 524 which is
2 preferably perforated. The lower longitudinal members and bottom
3 piece are preferably formed and spaced to provide a tray receptacle for
4 receiving and holding wafer tray 60. The tray receptacle is similar in
5 design to the construction employed in rotor 133, and the description
6 will not be repeated. The trays are slid into and retrieved from the
7 tray holder using the mechanical arm.

8 Dipper 507 is shown in Fig. 37 with the movable subassembly of
9 the dipper in a fully downward or submerged position in solid lines.
10 In this submerged position the wafers held in the wafer tray and tray
11 holder are capable of full insertion into tanks 501 or 502 to provide
12 full immersion or submersion in a bath of processing fluid (not shown).
13 Fig. 37 also shows in phantom lines the dipper movable assembly
14 positioned in an upward retracted position. Partial immersion positions
15 exist between a fully upward retracted position and the downward
16 submersion position shown for rear tank 502 in Fig. 37.

17 In operation, wafers held upon trays 60 are inserted into the
18 dipper basket and the mechanical arm tray holder is then retracted.
19 The dipper arm is then moved into the desired position to achieve
20 immersion of at least part, or more preferably full submersion, of the
21 wafers and tray into the desired processing bath contained in either
22 tank 501 or 502. The dipper driver can be controlled to jog the
23 wafers either horizontally or vertically and provide agitation of the
24 wafers within the bath of processing fluid. The wafers are left in the

desired immersion position until the desired processing has been accomplished. The wafers and associated tray are then moved by the dipper arm into an upward position wherein the processing chemical can drain back to the tank. Thereafter the movable dipper assembly is either held for removal of the wafers and trays, or moved into the second tank 501 or 502, as desired. The wafers are then processed in the second processing fluid until the desired processing has been completed. Thereafter the dipper arm is moved upwardly to withdraw the wafers from the processing bath and preferably left to drain briefly to conserve processing fluids. The wafer trays are then retrieved by the mechanical arm in a manner similar to that described above in connection with the retrieval of trays from rotor 133.

Operation and Methods

The operation and methodology of processor 40 has in part been explained above. Further description will now be given.

The invention further includes novel methods for processing semiconductor wafers and similar units requiring extremely low contamination. The methods can include providing a suitable processor, such as processor 40 described herein above and the associated subsystems thereof. Novel methods of processing such units preferably are performed by loading the wafers or other units to the system in carriers, such as wafer carriers 51. Such loading step is to a work space which is enclosed or substantially enclosed, such as working space

46. The loading step can include opening an enclosure door, such as door 59 of the interface port to allow entry of the wafers. The loading preferably is done by opening the enclosure door and extending a loading shelf through an open interface opening, such as port 56. Positioning of the loading shelf can be accomplished by moving the first carriage outwardly into an extended loading position.

The loading is further advantageously accomplished by depositing the wafers held within wafer carriers onto an extended loading shelf which is positioned through the interface opening. The wafers held in the carriers are positioned by depositing the loaded wafer carriers onto the extended shelf. The first carriage is thereafter moved such as by retracting the first carriage and the extended cantilevered shelf. After retracting the shelf through the interface port the methods advantageously include closing the interface port door or other similar enclosure door.

The methods also preferably include transferring wafers to a wafer tray, such as tray 60. Such transferring preferably is done by transferring the wafer from a wafer carrier and simultaneously onto the wafer tray. This is done by lifting the wafers from the wafer carrier using the wafer tray. The transferring is advantageously accomplished by extending the wafer tray through an opening in the wafer carrier, for example elevating the wafer tray up through a bottom opening in the wafer carrier to lift the wafers. The transferring preferably is accomplished using an array of wafer receivers, such as receivers 66.

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1 with the tray. The extending can function by lifting the engaged head
2 and then moving to dislocate the lifted tray from the storage area.
3 This dislocating can most easily be accomplished by moving the storage
4 area, such as by moving the second carriage 102, most preferably by
5 retracting the carriage.

6 The steps preceding the transferring step can also advantageously
7 include passing the engaged wafer tray through a pass-through opening
8 in the first carriage. The passing-through step can be accomplished by
9 lowering or retracting the engaged wafer trays through the pass-through
10 opening and thus placing the wafer tray in a position suitable for
11 performing the transferring. The passing-through most preferably
12 includes aligning the engaged wafer tray with the pass-through opening.

13 The steps preceding the transferring and installing process also
14 preferably include relatively moving the engaged wafer trays relative to
15 the wafer carriers to bring the engaged wafer trays into aligned
16 position. This aligning step is most ideally done by retracting ~~or~~
17 otherwise moving the first carriage rearwardly until the wafer carrier
18 opening and engaged wafer tray are aligned for transfer and installation.

19 After the transferring or other installing of the wafers onto the
20 wafer trays, the loaded wafer trays are preferably inventoried, such as
21 by holding upon the second carriage. This storing is in the preferred
22 embodiments done by extending or otherwise moving the second carriage
23 or other loaded tray storage relative to the loaded wafer trays. The
24 loaded wafer trays can be stored by positioning them over a holding

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1 features such as holding receptacles 125. The positioning can be
2 followed by lowering the wafer trays into the holders and then
3 supporting the wafer trays by the wafer holders.

4 The loaded wafer trays can then be processed further by loading
5 the wafer tray onto a wafer conveyor, such as conveyor 140. The
6 loading onto the conveyor can be done by moving a wafer tray
7 engagement tool into engagement with the tray. This engaging step is
8 most preferably done by sliding portions of the wafer engagement tool
9 along receiving features of the wafer tray, such as by sliding the
10 engagement edges 183 along receiving channels 83 of the tray, most
11 preferably along opposing sides of the wafer tray. The engaging can
12 further be perfected by lifting or otherwise interengaging the wafer tray
13 engagement tool with the wafer tray being moved. This is most
14 preferably done by lifting the tool relative to the tray and thereby
15 positioning a longitudinal engagement feature, such as tines 184, against
16 a complementary surface of the tray so that longitudinal or other lateral
17 displacement of the tray upon the tool does not occur due to
18 movement.

19 The methods also preferably include moving the wafer trays to
20 one or more processing stations. The moving can be done by tramming
21 the loaded wafer tray along a defined guide track upon a movable
22 tram. The moving or conveying step can also include horizontally
23 positioning the wafer tray, and vertically positioning the wafer tray, and
24 orienting the angular orientation of the wafer tray to enable the wafer

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1 tray to be positioned into a processing chamber. This functioning is
2 preferably followed by loading the wafer tray into the processing
3 chamber. This loading can be done by inserting the loaded wafer tray
4 into a centrifugal wafer tray rotor. The inserting or other loading step
5 can best be accomplished by sliding the loaded wafer tray into an
6 engaged relationship with the rotor by receiving interengaging parts of
7 the rotor and wafer tray.

8 The wafers which were inserted or otherwise installed into the
9 processing chamber are then preferably further treated by processing
10 with fluid processing materials, such as chemical processing fluids, liquid
11 or gas; or heating, cooling or drying fluids, most typically gases.

12 The processing can also advantageously be centrifugal processing
13 which involves rotating or otherwise spinning the wafers being processed,
14 particularly when still installed upon the wafer trays. The spinning
15 preferably occurs with the wafers positioned within a rotor which
16 performs a restraining function keeping the wafers in an aligned array
17 centered near the axis of rotation. The centrifugal processing can
18 include a variety of spinning, spraying, rinsing and drying phases as
19 desired for the particular articles being processed. Additional preferred
20 processing parameters are included in the appendix hereto.

21 The processing can also include immersion processing, such as can
22 be performed by the immersion processing station 414 described above.
23 Immersion station 414 or other suitable station can perform processes
24 which include positioning a dipper so as to allow installation of a

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1 The methods of this invention also include unloading the wafer
2 trays from the processing stations, such as by engaging the loaded wafer
3 trays with a tray engagement tool in processes similar to those discussed
4 above. The engaged and loaded wafer tray is then preferably processed
5 by relocating the wafer tray to a second processing station, such as by
6 conveying by moving with the mechanical arm assembly. The relocating
7 can include withdrawing the wafer tray from the processing chamber and
8 moving to another processing chamber and installing the wafer*tray
9 therein. The processing can then be furthered using a processing
10 sequence similar to that described or in other processing steps desired.

11 The wafer trays are also handled by conveying the wafer trays
12 and supported wafers to a holding station and holding the wafers
13 thereat. The holding awaits an interface unloading sequence which can
14 be accomplished by transferring the wafer trays and supported wafers
15 from the wafer trays back to wafer carriers. The transferring or
16 retransferring step back to the wafer carriers is essentially a reverse of
17 the transferring and installing steps described above. Such
18 advantageously includes unloading the wafer trays from the holding area,
19 such as by lifting loaded wafer trays from the holding receptacles. The
20 lifting or other removing of the wafer trays from the holders is
21 advantageously done by extending an elevator head through an aligned
22 wafer carrier and elevating the wafer trays. The holders are then
23 moved in a relative fashion from the lifted or otherwise supported wafer
24 trays. This is advantageously done by moving the second wafer

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1 carriage, such as by retracting the wafer carriage rearwardly away from
2 the supported wafer trays. The relative moving of the removed loaded
3 wafer trays and holders allows the wafer trays to be lowered or
4 otherwise retracted. The retracting is best performed by lowering the
5 wafer tray downward after aligning the wafer tray with a wafer carrier.
6 The lowering causes a transferring of wafers from the wafer trays onto
7 the wafer carrier.

8 The methods also preferably include retracting the elevators
9 downwardly and beneath the first carriage with the supported and now
10 unloaded wafer trays thereon. The first carriage can then be moved
11 into the pass-through position by aligning the empty wafer tray with the
12 pass-through opening. The empty trays can then be extended, such as
13 upwardly, through the pass-through opening.

14 The methods then preferably include moving the transferred wafers
15 held in the wafer carriers into an extended unloading position through
16 the interface port. This is advantageously done by moving the first
17 carriage forwardly and extending the cantilevered shelf out through the
18 interface port.

19 The moving of the first carriage forwardly to accomplish
20 unloading, can also be used to perform a storing function for the empty
21 wafer trays into the empty wafer storage array. This is preferably done
22 by elevating the wafer trays into an aligned storage position, such as
23 at a desired aligned storage elevation and then moving the first carriage
24 and attached storage gallery toward the engaged empty wafer tray.

1 Once installed the empty wafer tray can be lowered into a storage
2 position. The empty wafer trays are preferably stored in a downwardly
3 progressing fashion when the elevator is used.

4 The wafer carriers and associated processed wafers are taken from
5 the processor by removing the loaded wafer carrier from the
6 cantilevered shelf after such has been extended out through the
7 interface port or other unloading passageway. This is typically done by
8 manually grasping the wafer carrier with the processed wafers therein.

10 Alternative Embodiment Loading Subsystem

11 Figs. 40-49 illustrate an alternative preferred input and output
12 loading subsystem 600 according to this invention. Fig. 40 in particular
13 shows the important parts of this loading subsystem in isolation from
14 other parts of a system otherwise similar to processing system 40.
15 Figs. 41-49 show schematic representations of an alternative processing
16 system otherwise similar to processor 40 which has been adapted to
17 include loading subsystem 600. Various operational steps or phases are
18 illustrated in Figs. 41-49.

19 Fig. 40 shows the preferred loading subsystem 600. Loading
20 subsystem 600 is specifically adapted for unloading wafers held within
21 a wafer container 602. Wafer container 602 is advantageously a sealed
22 container having an upper or bonnet portion 604 and a base 603.
23 Bonnet 604 is secured to base 603 in a sealed relationship. A handle
24 605 is advantageously included for convenience in carrying the container.

1 Container 602 also preferably includes a removable bottom panel 610
2 which is shown disconnected in Fig. 40. When fully assembled the
3 wafer container 51 and enclosed wafers 50 rest on removable panel 610
4 and are held within container 602. Carrier 51 is shown in phantom
5 lines in Fig. 40 when installed and supported in the fully closed
6 position illustrated in Fig. 41.

7 Loading subsystem 600 also includes a container operator 608
8 which forms part of the docking station which receives the container
9 602. Container operator 608 includes a movable panel support 609
10 which is capable of moving upwardly and downwardly relative to the
11 supporting framework 41. Fig. 40 shows the movable panel support 609
12 in a downward position with the detachable panel from the wafer
13 container position thereon. In this position, wafer carrier 51 is
14 available for removal or installation as will be more fully described
15 hereinafter.

16 Fig. 40 also shows a wafer carrier loading subsystem relay
17 mechanism 613. Relay mechanism 613 includes the relay arm 614. A
18 lateral extension 615 extends from the distal end of arm 614 outwardly
19 to support a relay engagement head 616. Relay engagement head 616
20 is adapted to mechanically engage with wafer carrier 51 for secure
21 movement. Arm 614 is driven in a pivotal manner to swing from
22 downwardly extending positions to laterally extending positions as shown
23 in the figures. This is accomplished using a relay pivot drive 619
24 which is supported on a relay pivot drive support bracket 620. Relay

1 pivot drive 619 is advantageously a combined brushless direct current
2 motor and harmonic drive speed reducing output unit which is connected
3 to arm 614.

4 The relay engagement head 616 includes an engagement head
5 frame 621. Engagement head frame 621 includes two opposing inwardly
6 directed retaining catches or dogs 618 which catch beneath the upper
7 lips or phalanges formed on the upper portion of wafer carrier 51. As
8 shown, catches 618 are stationary elements which hold the end of the
9 wafer carrier nearest the viewer in Fig. 40. The opposite end of wafer
10 carrier 51 is held by two controllably movable catches 617. Catches
11 617 are advantageously vacuum operated catches having an extendible
12 locking pin (not shown). The locking pins are spring biased into a
13 catching position and operated by vacuum operators contained within
14 part 617 in order to release the locking pins. Catch dog 618 and
15 controllable catch or latch assembly 617 allow the carrier 51 to be
16 securely held by engagement head 616. Installation and ^{removal} ~~removal~~ of
17 carrier 51 from engagement head 616 involves release of catches 617
18 and small lengthwise displacement of carrier 51 relative to catches 618
19 to allow engagement or disengagement of the carrier from the head.

20 Methods according to this invention will now be described in
21 connection with the various unloading positions shown in Figs. 41-49.
22 The methods include engaging a sealed wafer container, such as
23 container 602, with the docking station, specifically by placement of base
24 603 upon docking station operator 608. The container is positioned

1 over the movable panel support 609. Fig. 41 shows container 602
2 properly located in the docking engagement position.

3 Fig. 41 also shows carrier loading relay 613 displaced a sufficient
4 amount to allow the panel support piece 609 to extend downwardly
5 from its upward closed position indicated in Fig. 41. Fig. 42 shows
6 support member 609 moved downwardly with the removable panel 610
7 and wafer carrier 51 supported thereon on member 609. This opening
8 of the sealed wafer container causes the interior of container 602 to be
9 placed in fluid communication with the contained working space within
10 enclosure 45. This opening process also includes opening an interface
11 port which is provided by the movable panel support member 609.
12 Member 609 is effectively the entrance and exit door between the
13 docking station and the enclosed work space.

14 Movement of member 609 also effects moving of the wafers
15 between the sealed container 602 and the enclosed work space. This
16 is true in both the loading and unloading processes performed.

17 Preferred methods for loading according to this invention further
18 include relaying or otherwise moving the wafers from the docking station
19 to a transfer apparatus within the semiconductor processing system
20 working area. Figs. 43-47 demonstrate this process. Fig. 43 shows
21 relay 613 pivoted into an engagement position with head 616 engaged
22 with wafer carrier 51 in preparation for movement by relay 613.
23 Fig. 44 shows the relay arm pivoted and supported wafer carrier 51
24 partially relocated and removed from the support piece 609. As arm

614 pivots, the wafer carrier 51 is reoriented from an end-down position to a bottom-down position as best illustrated in Fig. 40.

Fig. 45 shows the wafer carrier in a position extended upwardly in preparation for relocation of the first carriage 100. First carriage shelf 101 is moved from the position of Fig. 45, forwardly to obtain a position beneath wafer carrier 51 to provide support therefor. Fig. 46 shows first carriage 100 repositioned so that the first carriage support shelf 101 is beneath wafer carrier 51 in preparation for depositing the wafer carrier thereon.

Fig. 47 shows relay arm 614 lowered to deposit the wafer carrier upon shelf 101. Fig. 48 shows relay arm 614 pivoted into a downwardly retracted position. Fig. 49 shows wafer transfer robot 157 in position to engage wafer carrier 51 for movement to a desired processing chamber. This is appropriate if the processing chambers are adapted to receive the carriers and enclosed wafers directly. Alternatively and more preferably, wafer carrier 51 can be subjected to the transfer process as described hereinabove wherein the wafers are taken from wafer carrier 51 and deposited onto wafer tray 60. The wafers and supporting tray are then processed as described above.

The invention also includes novel unloading processes which are the converse of the loading processes described above.

In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not

1 limited to the specific features shown and described, since the means
2 herein disclosed comprise preferred forms of putting the invention into
3 effect. The invention is, therefore, claimed in any of its forms or
4 modifications within the proper scope of the appended claims
5 appropriately interpreted in accordance with the doctrine of equivalents.
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